

Indoor Air Quality Issues for Foundries

Introduction

An estimated 2,950 foundries are located throughout the U.S. and employ more than 225,000 people. These foundries cast a variety of metals into products that touch our lives everyday. Although the industry consists of many smaller operations serving specific market niches, there are also a few large "captive" foundries producing substantial volumes of castings for markets such as the automotive sector.

The foundry industry is changing. In the last decade, there have been enormous shifts in metal mix, increased government regulation, more international competition, and the introduction of new materials and process technologies. Along with these changes have come requirements to minimize environmental emissions both inside and outside the casting facility. The focus of this report is indoor air quality; a look at the important issues, and some suggestions leading to workable solutions.

Background

In 1999, American foundries shipped 14.4 million tons (13.1 million metric tons) of

State	Percent of Tonnage Shipped, 1999
Ohio	16%
Indiana	12%
Wisconsin	12%
Alabama	11%
Michigan	10%
Pennsylvania	6%
Illinois	6%
Tennessee	4%
California	4%
Texas	3%

Source: AFS

Table 1. Geographic Distribution of Foundries - Top Ten States

products valued at \$29 billion. The industry is centered in the Midwest, though there are foundries located in all 50 states. Table 1 shows the top ten foundry states and the percent of total tonnage shipped in the U.S.

Historically, locations for metal casting establishments were selected for their proximity to raw materials (iron, steel and other metals), coal, and water for process cooling and transportation. In recent years, the geographic concentration of the industry is changing as facilities are built where scrap metal and electricity are available at a reasonable cost and there is a local market for cast products.

The overall market for metal castings is projected to grow just under 2 percent annually for the foreseeable future. Efforts to reduce weight in parts cast for the automotive sector are not only changing the metal mix from iron and steel to aluminum and magnesium, they are also opening the door to high performance plastics and composites. In 1980, every domestically produced car used an average of 600 pounds (272 kg) of cast iron. By 1999, the average amount of cast iron per vehicle dropped to 325 pounds (147 kg). By 2006, it is expected that the amount of cast iron per car will slip further to 230 pounds (104 kg).

Though iron castings made up nearly 75 percent of all castings produced in 1999, this number is expected to decline as the market shifts to lighter metals. The principal growth market is in aluminum castings, which are

End-Use Markets	Percent of Castings Shipped
Automotive & Light Truck	35%
Pipe & Pipe Fittings	15%
Construction, Mining & Oil Field Equipment	6%
Internal Combustion Engines	5%
Railroad	5%
Valves	5%
Farm Machinery	3%
Municipal Castings (manhole covers, grates, etc.)	3%
Pumps & Compressors	2%
Other Markets	21%

Source: AFS

Table 2. End-Use Applications for Foundry Projects

projected to increase 4 percent annually for the next ten years. The metal mix in the foundry industry for 1999 is shown in Figure 1.

Metal castings are used in a variety of applications. More than 90% of all manufactured goods and capital equipment use castings as engineered components or rely on castings for their manufacture. Nearly one-third of all metal castings is produced for the automotive and light truck market. Other major end-use markets include pipe & fittings, construction mining and oil equipment, internal combustion engines, railroad, and valves. A breakdown of these markets is shown in Table 2.

The SIC codes included in the foundry industry are listed below.

SIC 3321 – Gray and Ductile Iron Foundries

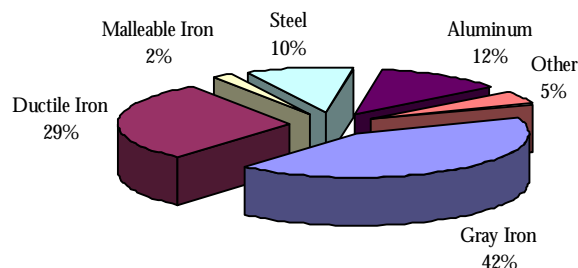


Figure 1. 1999 Casting Shipments - Percent of Sales

SIC 3322 – Malleable Iron Foundries
 SIC 3323 – Steel Investment Casting Foundries
 SIC 3325 – Steel Foundries, not elsewhere classified
 SIC 3365 – Aluminum Foundries
 SIC 3366 – Copper Foundries
 SIC 3369 – Nonferrous Foundries, not elsewhere classified

According to the U.S. Census bureau, more than 50 percent of all foundries operating today have less than 50 employees, and 80 percent employ fewer than 100 employees. Only 6 percent employ more than 250 people. Notable among the larger facilities are the “captive” foundries operated by original equipment manufacturers, including General Motors, Ford, Chrysler, John Deere, and Caterpillar.

Economic Trends and Development Needs

The U.S. metal casting industry experienced an unprecedented drop in production during the 1970's and 1980's, but has been recovering since the early 1990's. Between 1993 and 1994 alone, the U.S. increased its share of world metal casting production from 18 to 20 percent. The increases in production came primarily from increases in capacity utilization at existing facilities rather than the construction of new facilities.

To stay competitive, the industry has identified the following priority areas for research and development to improve its processes and products:

- improved casting technologies
- development of new casting materials (alloys) and die materials
- development of higher strength and lower weight castings
- improved process controls
- improved dimensional control
- improved the quality of casting material
- reduced casting defects (DOE, March 1996)
- development of environmentally improved materials to meet today's regulations.

Challenge

Today it is critical that the industry be familiar with the environmental hazards that employees are subjected to in the workplace. Emission levels for foundry operations have been thoroughly reviewed by the Environmental Protection Agency (EPA), the Occupational Safety and Health Administration (OSHA), and Burgess (Health Hazards in Industry, 1995). Exposures to mineral dusts, metal fumes, products of combustion, resin bonding systems, physical noise, heat and vibration hazards may seriously impact the health of workers in foundries. Silica, a major component of sand, can be converted to forms that cause silicosis in workers. Data from several hundred foundries found airborne concentrations above the OSHA Permissible Exposure Limit (PEL) in 31 to 54 percent of the samples taken. The challenge that foundries face today is to produce a cost competitive product while taking all necessary precautions to protect the health and safety of its workforce.

In addition, the Department of Energy's Office of Industrial Technologies has prepared a Technology Roadmap of the Metalcasting Industry as part of the Industries of the Future program. This roadmap notes that environmental needs are one of the four key needs for the future of that industry. This roadmap was developed with the support of the metal casting industry, including the American Foundrymen's Society, the North American Die Casting Association and the Steel Founders' Society of America.

Environmental Standards and Regulations

On November 15, 1990, President Bush signed into law the first changes to the Clean Air Act in 13 years. The new legislation affects smaller foundries that were not previously regulated. Any metal caster producing more than 10 tons (9.1 metric tons) of air toxics per year, or more than 25 tons (22.7 metric tons) per year of a combination of listed chemicals is included under the new standards. The EPA established a list of source categories of toxic air pollutants

as one that emits 10 tons (9.1 metric tons) per year of a single substance or 25 tons (22.7 metric tons) per year of any combination of substances.

Exposure sources and chemicals of concern taken from EPA reports, including the latest version of AP-42, are summarized in Table 3. The types of emissions generated, by process operation, are also listed in Table 3.

The green sand molding process is the most common molding process, accounting for nearly 90% of castings produced in the U.S. An example of emissions by process operation is shown in Figure 2.

Investigation into OSHA records for the most recent 100 facility audits for the Iron and Steel foundries provides some additional insights into the air quality issues affecting foundries. Foundries reported an incident and injury rate of 21.5 per 100 workers in comparison to the national average of 8.8 for all manufacturers. The foundry SIC codes range from a low of 12.8 injuries (SIC 3324) to a high of 25.4 injuries (SIC 3322) per 100 workers.

In reviewing 400 audits, 1,392 violations were sorted by reported violation. Violations pertaining to indoor air quality (IAQ) are summarized in Table 4.

Approximately 23% of the total violations are related to airborne contaminants in the workspace. The chemicals of concern include asbestos, organics, metal fumes and particulates such as silica dust.

There were 52,500 reported lost workday cases for SIC 33 in 1998 for a total industry employment of 714,200 workers. The foundry industry employs about 110,000 workers with lost time of just over 8,000 work days. Assuming each worker costs \$30/hour, and that 15 - 25% of the lost days were related to IAQ, the annual cost for the industry approaches \$1 - 2 million per year. And this is just the reported cases.

Indoor Air Quality Regulations

Many different organizations have regulations and/or standards that are used to determine the adequacy of the indoor air environment. These organizations, their pertinent rules and/or regulations and the areas of indoor environment they address are summarized below.

Industrial Process	Air Emissions
Pattern Making	Volatile Organic Carbons (VOCs) from glues, plastic resins, urethane adhesives, epoxies and paints
Mold and Core Preparation and Pouring	
Green Sand	Silica and other particulates, metal oxide fumes, carbon monoxide, organic compounds, hydrogen sulfide, sulfur dioxide and nitrous oxide. Also, benzene, phenols, formaldehydes and other hazardous air pollutants (HAPs) if chemically bonded cores are used. Particulate emissions are generated during mixing, molding and core making operations. When green sand additives and core sand binders come into contact with the molten metal, they produce gaseous emissions such as carbon monoxide, organic compounds, hydrogen sulfide, sulfur dioxide, nitrous oxide, benzene, toluene, xylenes, phenols and other HAPs.
Permanent Mold	Compared to sand casting operations, relatively little waste is generated in the permanent mold process. Fugitive silica dust and waste sand/plaster (particulates and metallic oxide fumes) are generated if cores are fabricated of sand or plaster respectively.
Plaster Mold	Waste mold plaster and fugitive dusts (particulate) and metallic oxide fumes can be generated using this molding process.
Investment/Lost Wax	Waste refractory material, waxes and plastic are the largest volume wastes generated. Air emissions are primarily silica particulates and metallic oxide fumes from this process.
Lost Foam	Large quantities of polystyrene vapors are produced during lost foam casting. They can be flammable and may contain metallic oxide fumes, methane, acetylene, carbon monoxide, hydrogen and hazardous air pollutants (HAPs) such as benzene and styrene. Sand particulates are another source of air emissions.
Chemical Binding Systems	Silica particulates, core oils, urea formaldehyde, phenol formaldehyde, furan, alkyl isocyanate, phenolic isocyanate, polyester urethane, phosphoric acid, toluenesulfonic acid and benzenesulfonic acid.
Furnace Charge Preparation and Metal Melting	
Charging and Melting	Cupola, reverberatory and electric arc furnaces may emit particulate matter, carbon monoxide, hydrocarbons, sulfur dioxide, nitrogen oxides, small quantities of chloride and fluoride compounds, and metallic fumes from the condensation of volatilized metal and metal oxides. Cupola furnaces emit the most organic and inorganic toxic emissions of all melting furnaces. Induction furnaces and crucible furnaces emit relatively small amounts of particulates, hydrocarbon, and carbon monoxide emissions. The highest concentration of furnace emissions occur when furnaces are opened for charging, alloying, slag removal and tapping.
Fluxing and Slag and Dross Removal	Particulates, metallic oxide (e.g., magnesium oxides) fumes, solvents, hydrochloric acid.
Pouring	Emissions of particulates, lead, arsenic, chromium, halogenated hydrocarbons and aromatic hydrocarbons
Quenching, Finishing, Cleaning and Coating	
Painting and Rust Inhibitor Application	VOCs. Finishing operations may generate particulate air emissions. Cleaning and coating may generate air emissions of VOCs from painting, coating and solvent cleaning; acid mists and metal ion mists from anodizing, plating, polishing, hot dip coating, etching and chemical conversion coating.
Shakeout, Cooling and Sand Handling	Silica dust and metallic particulates; VOC and organic compounds from thermal sand treatment systems. Shakeout, cooling and sand handling operations generate waste sand and fines possibly contain metals.
Cleaning, Quenching, Grinding, Cutting	VOCs, silica and other dusts and metallic particulates

Table 3. Air Emissions by Foundry Process Operation

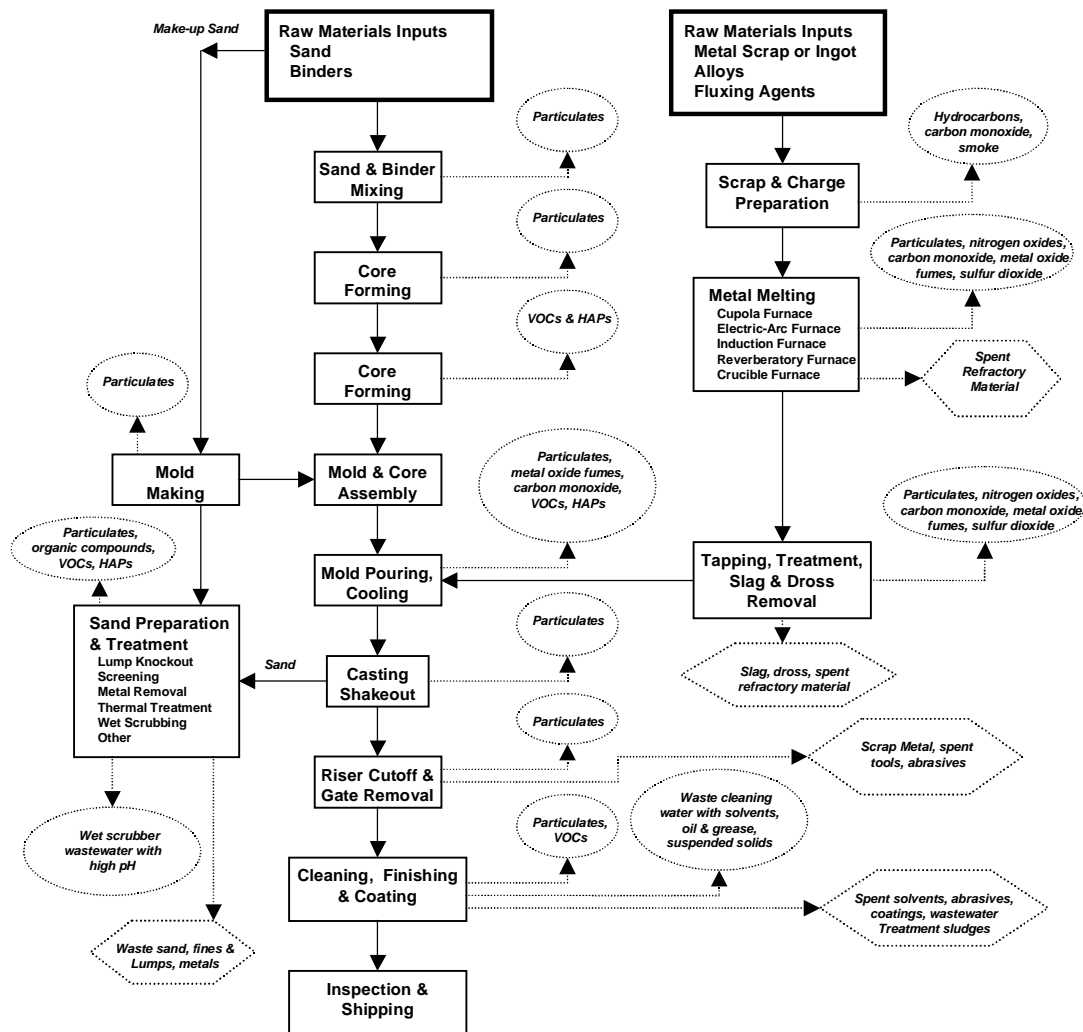


Figure 2. Sources of Emissions from Green Sand Foundry Operations (EPA/310-R-97-004, 1998)

OSHA Violation	SIC				Number of Violations	%
	3321	3322	3324	3325		
Air Contaminants (not specified)	10	14	14	15	53	3.8
Asbestos	0	1	0	4	5	0.4
Flammable/Combustible Liquids	1	5	10	9	25	1.8
Chemicals (acetylene, lead, cadmium, formaldehyde, methylenedianiline)	17	19	19	4	59	4.2
Noise	4	20	14	9	47	3.4
Personal Protective Equipment (PPE) - General	2	16	17	18	53	3.8
Respiratory Protection	10	13	24	27	74	5.3
Ventilation	0	1	3	0	4	0.3
TOTALS	44	89	101	86	320	23.0

Table 4. OSHA Indoor Air Quality Related Violations, Iron and Steel Foundries

- American Conference of Governmental Industrial Hygienists (ACGIH), *Threshold Limit Values (TLVs)* sets limits for acceptable 8-hour exposure to over 600 chemicals.
- American Society of Air Conditioning, Heating and Refrigeration Engineers (ASHRAE), *55-1992, Thermal Environmental Conditions for Human Occupancy* publishes standards for combinations of temperature and humidity depending on time of year and clothing worn.
- ASHRAE, *62-1999, Ventilation for Acceptable Indoor Air Quality* publishes standards for acceptable ventilation rates to residential and commercial spaces to minimize the buildup of indoor air contaminants.

- Key sections in the Environmental Protection Agency (EPA), *40 CFR Parts 50-99, Clean Air Act* are the National Emission Standards for Hazardous Air Pollutants (NESHAPs) - 40 CFR 61 Subpart M.
- EPA, *40 CFR Parts 302, 355, 370 and 372, Superfund Amendments and Reauthorization Act (SARA) Emergency Planning and Community Right to Know Act (EPCRA) of 1986 provisions* requires certain facilities to collect data and prepare reports on certain materials [usually greater than 5 tons (4.5 metric tons)] for the State Emergency Response Commission (SERC) and the Local Emergency Planning Committee (LEPC). These include the annual Forms 311, 312 and R.
- EPA, *40 CFR Parts 700-799, Toxic Substances Control Act (TSCA)* contains provisions regarding the manufacturing and use of certain substances, including asbestos, lead, PCBs and radon.
- National Institute for Occupational Safety and Health (NIOSH), *Recommended Exposure Limits (RELs)* has RELs for over 160 hazardous substances.
- OSHA, *29 CFR Part 1910.1000, Acceptable Levels for Air Contaminants and Mineral Dusts*, Tables Z-1, Z-2 and Z-3, June 7, 1988, rule proposed to add/amend 402 substances to these tables (total of about 430), mainly adding ACGIH values. New tables are expected to become law in 2 to 5 years based on July 30, 1999 notice.
- OSHA, *29 CFR Part 1910.94, Ventilation*, publishes occupational ventilation requirements.
- OSHA, *29 CFR Parts 1910.95, Occupational Noise Exposure* publishes acceptable noise levels with/without hearing protection.
- OSHA, *29 CFR Parts 1910.119, Process Safety Management (PSM) of Highly Hazardous Chemicals* is a companion rule to EPA's Risk Management Plan (RMP) rule. It publishes broad requirements on certain hazardous or flammable chemicals stored in certain quantities in the workplace.

- OSHA, *29 CFR Parts 1910.120, Hazardous Waste Operations and Emergency Response (HAZWOPER)* defines training and responses safely handling hazardous wastes.

Of all these regulations, the OSHA Table Z PELs are likely to have the most impact on the foundry industry. Air contaminants found in foundries and their Permissible Exposure Limits (PELs) are summarized in Table 5.

Legislation has also been written that subjects foundries to Maximum Achievable Control Technology (MACT) standards. These standards require foundries to install technology particular to the foundry industry that is providing the most effective reduction of environmental emissions. There has been considerable debate with regard to MACT standards which has delayed their implementation. It should also be noted that MACT standards are jointly designed by the EPA and foundry operators and apply principally to outdoor air quality. The first MACT draft for the foundry industry is due to be released by December, 2000.

Solutions and Recommendations

There are four principal methods to improve air quality that have been utilized in the foundry industry.

- General (Dilution) Ventilation
- Local Exhaust
- Worker Specific Protection
- Process Modification

These solutions revolve predominantly around the use of electrotechnologies, including motor driven fans for ventilation and induction for melting.

General Ventilation: The principle of general ventilation is to dilute airborne contaminants through air turnover. General ventilation, to be effective, has to move large amounts of air. This method is costly because of the volume of air that has to be moved, especially during winter when heated make-up air must replace exhausted air.

General ventilation is not the most effective means for controlling dust or vapors from localized areas. It can be used to provide cool air to workers in

hot environments (melting, pouring, shakeout) to minimize the effects of heat stress. The feasibility of this type of ventilation must be considered on a case by case basis.

Local Exhaust: Local exhaust/ventilation, in contrast to general ventilation, is designed to evacuate contaminated air from a specific area. A local exhaust system consists of a capture hood, connecting ductwork, air-cleaning device and fan. Local exhaust systems come in various designs depending on the type of operation that needs to be controlled.

The size of the work area may limit the use of a local exhaust system because costs escalate and efficiency becomes limited as the size of the system increases.

Overall, local exhaust ventilation is more efficient in controlling contaminant levels than general ventilation. There are a variety of suppliers who produce dust, fume, mist and smoke collectors designed for foundry applications. To

CHEMICAL	OSHA PEL (mg/m ³)
Acrolein	0.25
Benzene	10 ppm
Cadmium fume	0.1
Cadmium dust	0.2
Chromium compounds	0.5
Copper fume	0.1
Iron oxide fume	10
Magnesium oxide fume	15
Manganese fume	5
Nuisance Dust	
- Respirable fraction	5
- Total	15
Oil mist	5
Phenol	19
Silica	
- Quartz (respirable)	10 / (% SiO ₂ + 2)
- Quartz (total dust)	30 / (% SiO ₂ + 2)
- Cristobalite	half of values for quartz
- Tridymite	half of values for quartz
Silicon	
- Respirable fraction	5
- Total	15
Styrene	100 ppm
Sulfur dioxide	13
Toluene	200 ppm
Tellurium and compounds	0.1

Table 5. Foundry Air Contaminant Permissible Exposure Limits (PELs)

match the appropriate equipment to the application, it is suggested that system design be professionally evaluated. Examples of ventilation/filtering technologies include fabric, cyclone, downdraft benches and workcenters, smoke-fume, bag-dump stations, and bin (silo) vents.

Local ventilation can be used to remove dust/particulate at the following source locations: melting, metal casting/pouring, investment casting, annealing, quenching, tempering, abrasive blasting, finishing, degreasing, shakeout, coremaking, mold making, and sand reclamation.

Worker Specific Protection: Worker protection such as respirators are often used as a temporary measure while a long term solution is in the design/installation phase. Other protection such as gloves, special clothing and eye protection serve very specific purposes and can be effective when used in combination with other measures to minimize the potentially harmful effects of a foundry environment.

Air purifying respirators and air supplying respirators must be NIOSH/MSHA approved. Also, the cartridges and filters in air purifying respirators have limited capacity to absorb/trap contaminants and must be changed on a regular basis.

The toxicity effects of harmful substances, handling information, and recommended worker protection measures are listed on the material safety data sheets (MSDS). An MSDS sheet must, by law, accompany the shipment of any regulated substance as defined by NIOSH. The MSDS must be displayed and easily accessible to employees.

Process Modification:

- Induction furnaces and crucible furnaces emit relatively small amounts of particulates, hydrocarbons, and carbon monoxide emissions. It may be possible to replace older cupola, reverberatory or electric arc furnaces with induction or crucible melting.
- Modify the binder additive used in the sand molds. A new generation of binders has been developed to minimize phenol/formaldehyde content and subsequently lower VOC emissions. Binder emissions are a significant contributor to poor indoor air quality.
- Use binders that incorporate esters dissolvable in water rather than those based on phenolic compositions.
- Use furans or free radical-cured acrylic binders to reduce phenol/formaldehyde emissions.
- Use "cold box" processes and no-bake sands with higher molecular weight esters, yielding lower VOC emissions.
- Replace silica sands with olivine, zircon and chromite sands that have lower toxicity.
- Keep sand moisture content above 25% during molding.

Acknowledgements

Stephen Petty of Energy and Environmental Services, Inc. and Joe Fox of Ashland Chemical provided reference materials and valuable technical input.

Resources

The following OSHA publications are available free of charge:

OSHA – 2056. *All About OSHA*
OSHA – 2098. *OSHA Inspections*
OSHA – 3021. *OSHA: Employee Workplace Rights*
OSHA – 3084. *Chemical Hazard Communication*
OSHA – 3047. *Consultation Services for the Employer*
OSHA – 3071. *Job Hazard Analysis*
OSHA – 3077. *Personal Protective Equipment*
OSHA – 3079. *Respiratory Protection*
OSHA – 3085. *OSHA Computerized Information System (Chemical information file)*
Hazard Communication Standard, Title 29, Code of Federal Regulations (CFR) Part 1910.1200

Contact: OSHA Publications Office, Rm N 3101, 200 Constitution Avenue NW, Washington, D.C. 20210 Phone: (202) 523-9667

The following OSHA publication is available for a fee:

OSHA – 3104. *Hazard Communication Compliance Kit* – Contact Superintendent of Documents, US Government Printing Office, Washington, DC 20402 Phone: (202) 783-3238 (\$18 fee)

Other resources:

American Foundryman's Society (AFS), 505 State Street, Des Plaines, IL 60016 Phone: (800) 537-4237 www.afsinc.org

Ashland Chemical Safe Foundry Manual, available through the Foundry Products Division, 5200 Blazer Memorial Parkway, Dublin Ohio 43017 Phone: (614) 790-3333

Casting Emissions Reduction Program (CERP), McClellan Air Force Base, 5301 Price Avenue, Bldg 238, McClellan AFB, CA 95652-2502 Phone: (916) 643-1090 www.cerp-aiger.org

Metal Casting Industry Roadmap, Office of Industrial Technologies, DOE, 1000 Independence Ave. SW, Washington, DC 20585 Phone: (202) 586-9235 www.oit.doe.gov/metallcast

Applicable SIC Codes:

3321, 3322, 3323, 3325, 3365, 3366, 3369

To order additional copies of this publication call 800.313.3774 or e-mail askepri@epri.com.

© 2000 Electric Power Research Institute (EPRI), Inc.

All rights reserved, Electric Power Research Institute and EPRI are registered service marks of the Electric Power Research Institute, Inc. EPRI. POWERING PROGRESS is a service mark of the Electric Power Research Institute, Inc.

♻️ Printed on recycled paper in the United States of America.

00000000001000139

EPRI Center for Materials Production • 1251 Dublin Road • Columbus, OH 43215
614.421.3440 • cmp@tarateccorp.com

EPRI Corporate address • 3412 Hillview Avenue, Palo Alto, CA 94304 • PO Box 10412, Palo Alto, CA 94303 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com